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DEVELOPMENT OF EQUIPMENT TO DETERMINE THE SIZE AND DISTRIBUTION OF AIR BUBBLES IN FRESH CONCRETE

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ABSTRACT

This investigation describes a new method which is proposed to determine the air content and the size and distribution of air bubbles in fresh concrete. The method consists of taking an enlarged polaroid microscopic photograph of a specimen of fresh concrete and analyzing the photograph with Image Processing and Computer equipment. Preliminary tests were carried out and the results indicate that the method is satisfactory even though it is not practical as yet. However, there is good potential to develop the method further so that it can be used both in the laboratory and in the field.

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DEVELOPMENT OF EQUIPMENT TO DETERMINE THE SIZE AND DISTRIBUTION OF AIR BUBBLES IN FRESH CONCRETE

INTRODUCTION:

Durability of concrete exposed to freezing and thawing and to de-icing salts is dependent upon the strength of the concrete and the volume of entrained air therein. In general, the air content of the concrete is measured by either the pressure or the volumetric methods as recommended by the Canadian Standards Association, CSA. These methods are satisfactory except they do not give any indication of the size and distribution of the air bubbles in the fresh or hardened concrete. So it was deemed important and of practical significance to try and develop a new method that can fulfill all the above requirements: that is,to measure the volume, size, and distribution of air bubbles in fresh concrete. Preferably, the method should be applicable in the field and in the laboratory and should be easy to perform.

NEW METHOD:

The writer envisaged that a successful method can be developed by taking an enlarged polaroid picture of the fresh concrete and by analyzing it with both an image processer and a computer. A schematic diagram of a possible image processing system is illustrated in Fig. 1.

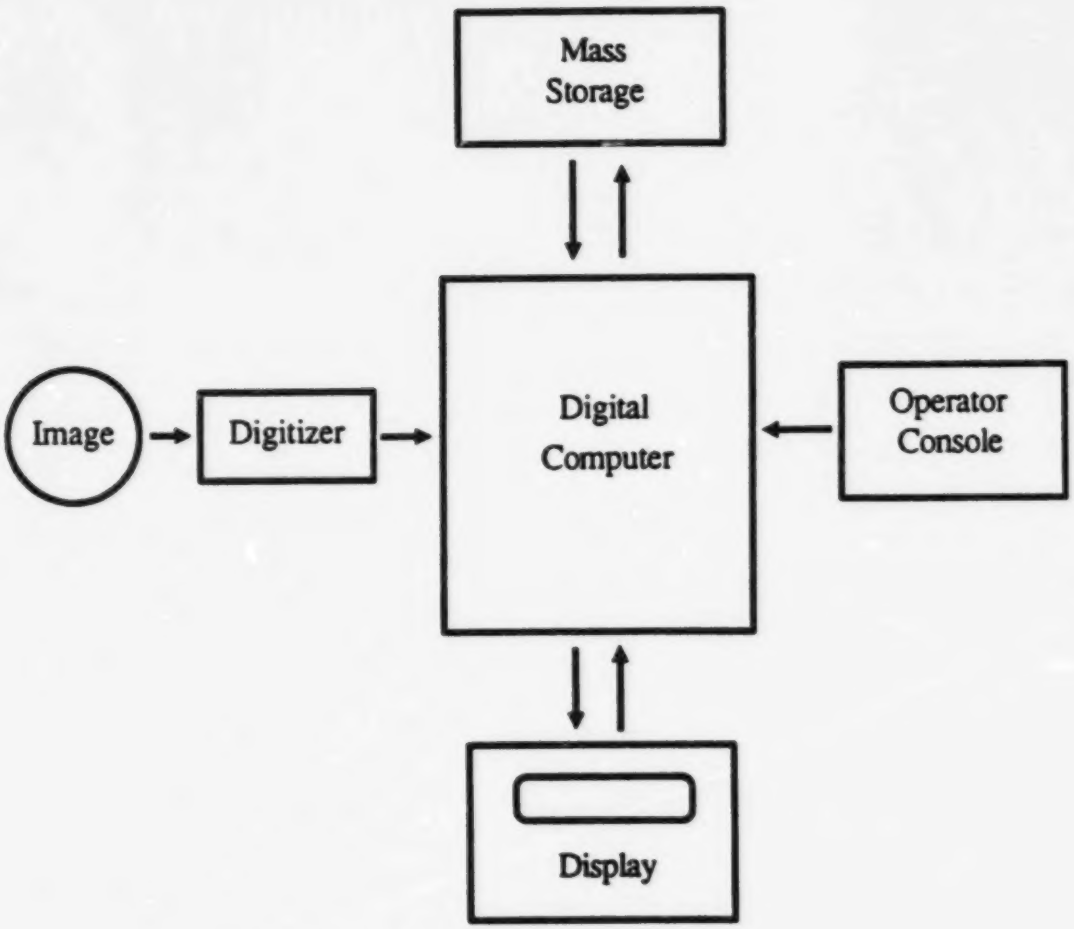


Fig. 1.

Diagram of a Digital Image Processing System

EQUIPMENT:

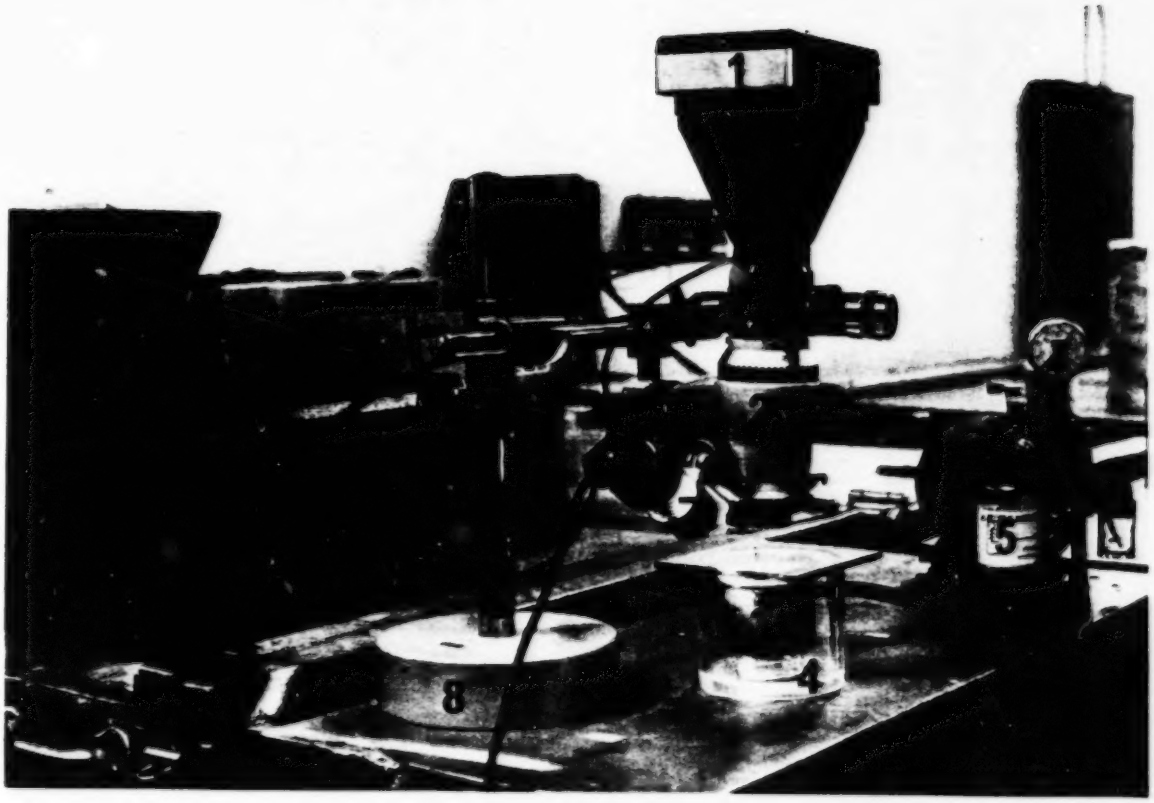
After several trials, the equipment that was chosen for the proposed method is shown in Figures 2 and 3. Description of the components in each figure are outlined below:

Figure 2. Picture of Photo-Microscopic Zoom System

Item	Description
1	Polaroid Camera
2	Microscopic zoom system
3	Fresh concrete container
4	Vacuum vessel
5	Vacuum pump
6	Light meter and exposure timer
7	Microscope lamp
8	Support for microscope system

Figure 3. Picture of Comtal Image Processor

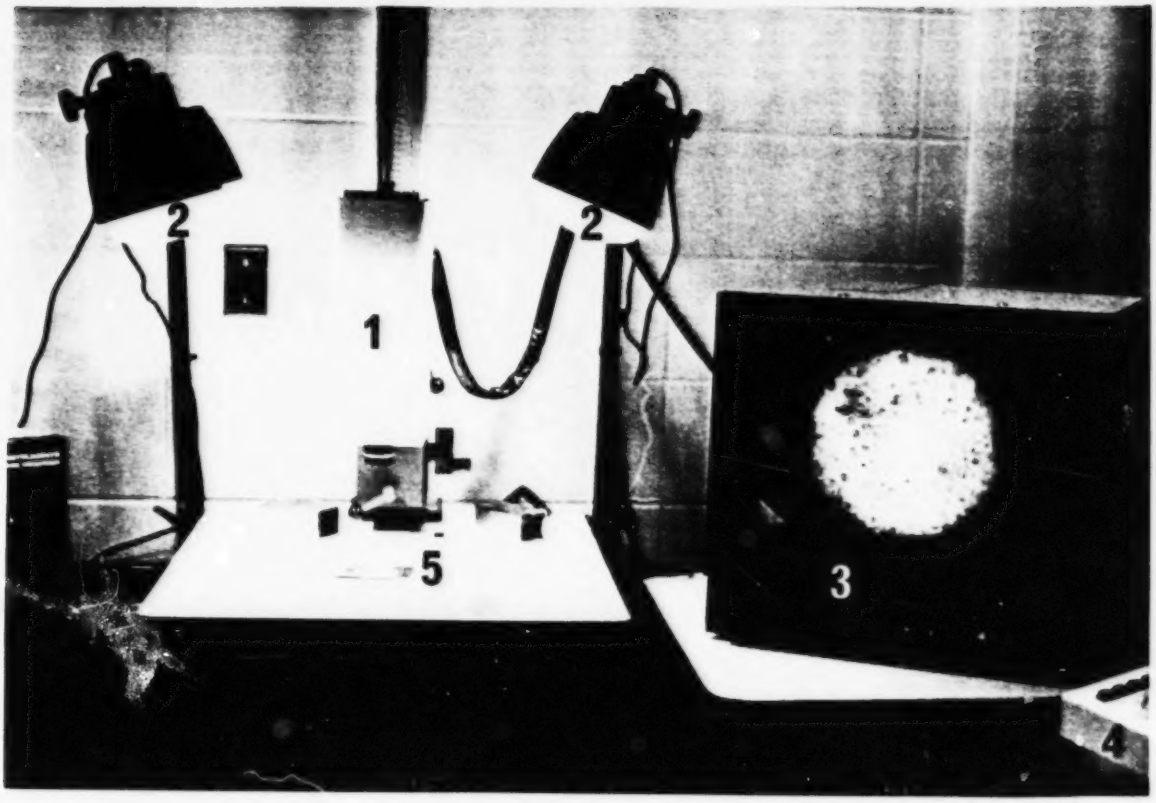
1	Camera
2	Lamps
3	Image Display Monitor
4	Computer
5	Polaroid photo of fresh concrete



1. Polaroid Camera
2. Microscopic Zoom System
3. Fresh Concrete Container
4. Vacuum Vessel
5. Vacuum Pump
6. Light Meter & Exposure Timer
7. Microscope Lamp
8. Support for Microscope System

Fig. 2.

Picture of Photo-Microscopic Zoom System



1. Camera
2. Lamps
3. Image Display Monitor
4. Computer
5. Polaroid Photo of Fresh Concrete

Fig. 3.

Picture of Comtal Image Processor

PROCEDURE:

A sample of fresh concrete is placed and compacted in a cylindrical container 3.0 in (75 mm) in diameter and 2.0 in (50 mm) long. Compaction is done by means of a 1/4 in (6 mm) rod. The concrete is placed in two equal layers and each layer is tamped 10 times. The side of the container is tamped 5 times to help remove the entrapped air in the concrete. The metal tamping rod is also used to level the surface of the concrete. Care is taken to make sure that the surface of the concrete is as smooth as possible as shown in Fig. 4. Next, the concrete container is placed in a vacuum plexiglass cylinder 4 in (100 mm) in diameter and 3 in (75 mm) long. A 5 in (125 mm) square glass plate 1/4 in (6 mm) thick is used to cover the plexiglass cylinder so as to seal the space around the concrete container in order to be able to apply a vacuum to the concrete. The concrete specimen is also positioned under the microscope in order to take its photo with the polaroid camera at the appropriate time. A vacuum of 570 mm of mercury is applied to the sample so as to help increase the size of the air bubbles and produce a better contrast in the picture. The microscope is next focused for a clear view of the surface of the concrete and then the lightmetre and the exposure timer are activated to prompt the camera to take a picture of the surface of the concrete as shown in Fig. 2. The most satisfactory picture that could be taken was that of a concrete surface 2.5 mm (0.10 in) in diameter which was magnified 22 times. The film that proved to be adequate in this investigation was a Polaroid Type 667, coaterless black and white Land film, with a speed of ISO 3000/36°. The processing time for the film is 30 seconds.

Fig. 4.

Picture of Fresh Concrete Specimen

IMAGE PROCESSING SYSTEM:

Once a picture is taken of the surface of the fresh concrete specimen, then that same picture will be analyzed by the image processing equipment. The picture is placed on the table in the focus range of the video camera. The lights and the position of the camera are adjusted so that the best view of the picture can be projected onto the monitor as shown in Fig. 3. The available image processing system in the Engineering College was a Comtal Vision One/20. This system produces a high spatial resolution video image over a full range of brightness levels in shades of grey. The system may be controlled by means of alpha-numeric keyboard in front of the monitor. The image processing system was interfaced with the VAX 11/780 computer available in the college. A listing of the program that was used is given in the Appendix. The program was written in Fortran 77 for compatibility with the Comtal subroutines. A line diagram of the program is presented in Fig. 5. As can be seen from Fig. 5, the program is divided into 3 phases:

Phase 1. Image generation

Phase 2. Image modification

Phase 3. Image analysis

In phase 1, the image is processed interactively by using the Comtal subroutines and the image is read into the VAX and converted to compatible signals. After the Comtal is allocated, the CMWINDOW subroutine defines the size of the image to be sent. A digital image is generated and followed by the CMCOPY subroutine.

In phase 2, a selected section of the digital image is modified and

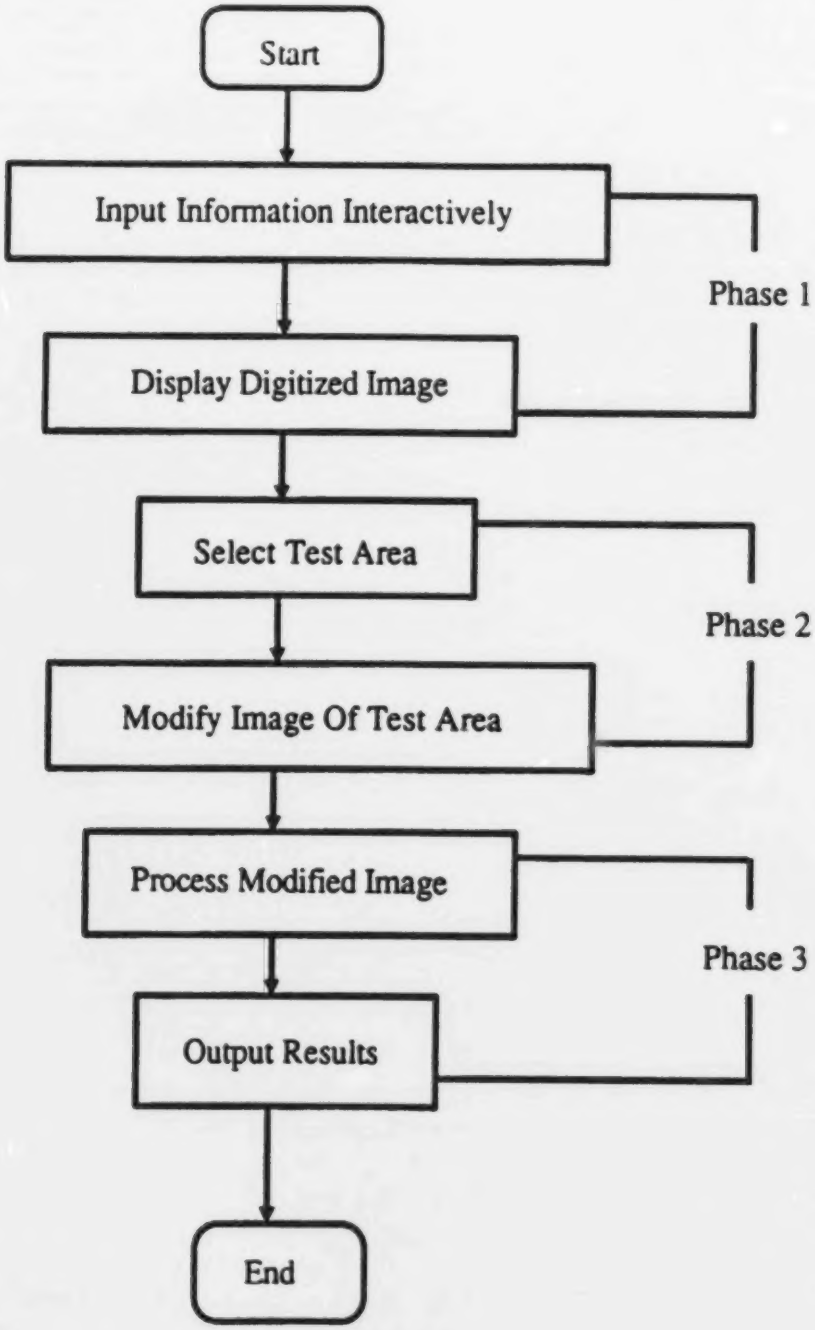


Fig. 5

Flow Chart of Image Digitization Method

enhanced so that the image can be analyzed. By studying the histogram of the unprocessed image, a direct histogram specification is first applied to modify the image's dynamic range or contrast. This is followed by a filtering technicque to reduce the blurring effect at the edges. Fig. 6 shows an enhanced image of a concrete sample; the black areas on the white background represent the air voids.

In phase 3, the processed image is scanned linearly, similar to the linear traverse method outlined in the American Society of Testing and Materials ASTM C457. Three separate spots on the picture were chosen at random and their image was processed and the average value determined from these spots was chosen as representative of the air-void system in the concrete. The percentage of air content can be calculated as the No. of black pixels divided by the total number of all pixels multiplied by 100. Other parameters of the air void system can then be calculated using Powers (1968) equations.

TESTING PROGRAM:

The testing program consisted of preparing a normal weight concrete mix with an aggregate cement ratio of 7, a water cement ratio of 0.56 and various air contents ranging from 1 to 7%. The air content in the fresh concrete was measured with the Mini Air Meter shown in Fig. 7. The same size specimen used in the Mini Air Meter was also used for the Image processing method. The air-void system in the fresh concrete was determined by the Image processing method, while that in the hardened concrete was determined by the linear traverse method as illustrated in Fig. 8. Comparison between the two methods was carried out as will be outlined

Fig. 6.

Filtering Technique in the Image Processing Method

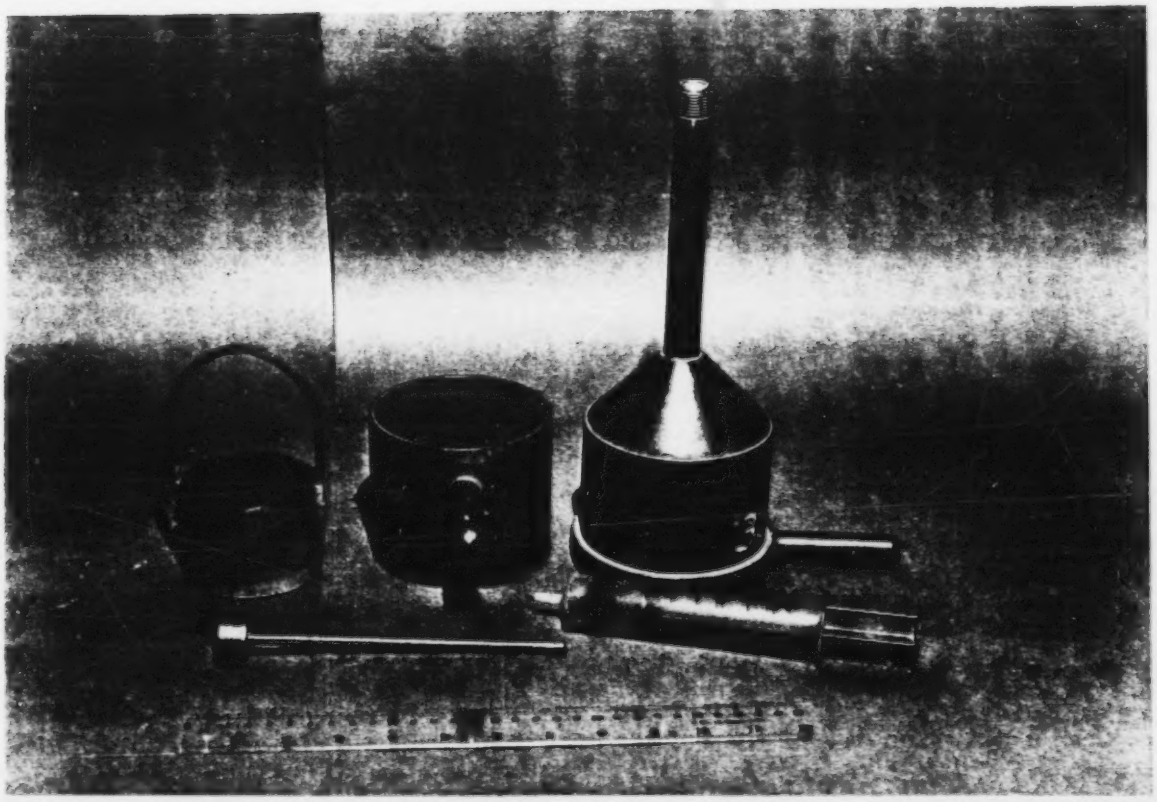


Fig. 7.

Mini Air Meter for Fresh Concrete

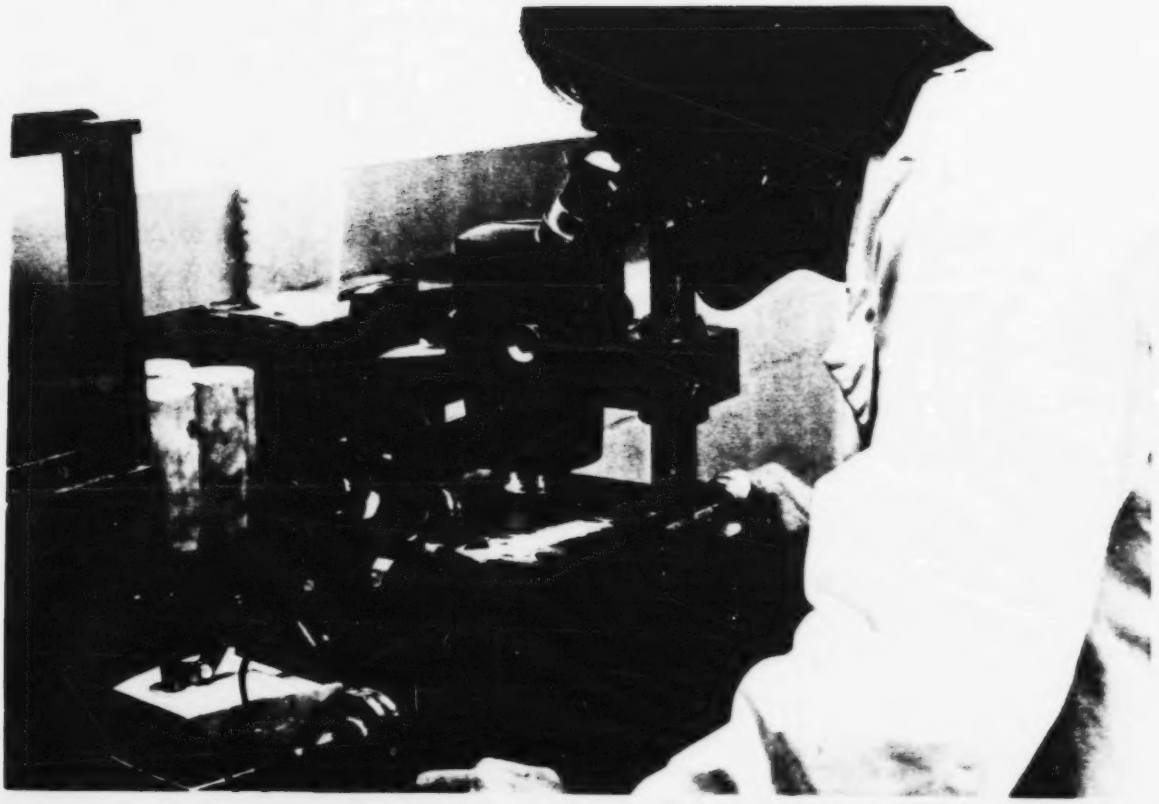


Fig. 8.

Linear Traverse Apparatus

later on. The materials that were used in the mix were type 1 cement, dolomite and hornblende aggregate with maximum size of 25 mm, air entraining agent and tap water. All the materials conformed to CSA and/or ASTM specifications as outlined in Tables 1 and 2. The consistency of the mixes ranged between 2 and 6 in (50 and 150 mm) slump, depending on the amount of air-entraining agent in the mix.

The specimens for the Linear traverse method were prepared from 3 x 6 in (75 x 150 mm) cylinders which were cut and polished to give a minimum viewing surface of 30 sq.in (18,750 sq.mm).

TEST RESULTS:

A summary of the test results is given in Table No.3 below:

Table 3. Summary of Results of Air Content, Diameter and Spacing Factor of the Air Bubbles in Concrete

Air Content %			Ave. Diam. mm		Spacing Factor mm	
Mini Air Meter	Micr. Linear Trav.	Image Proc.	Micr. Linear Trav.	Image Proc.	Micr. Linear Trav.	Image Proc.
1.50	0.48	2.26	0.120	0.043	0.040	0.070
2.95	3.10	4.04	0.065	0.059	0.093	0.077
5.86	4.71	5.04	0.078	0.073	0.091	0.085
7.99	5.43	6.45	0.078	0.072	0.073	0.073

Table 1. Chemical Analysis and Physical Properties of Portland Cement Type 1

CHEMICAL ANALYSIS		ASTM C 150 Specification
Silia (SiO_2)	21.19%	--
Alumina (Al_2O_3)	4.10%	--
Iron Oxide (Fe_2O_3)	2.34%	--
Calcium Oxide (CaO), Total	62.84%	--
Calcium Oxide (CaO), Free	0.99%	--
Magnesium Oxide (MgO)	4.56%	6.00 max
Sulphur Trioxide (SO_3)	2.56%	3.00 max
Loss on Ignition	1.40%	3.00 max
Insoluble Residue	0.20%	0.75 max
Available Alkalies as Na_2O	0.66%	--
Tricalcium Silicate (C_3S)	56.60%	--
Dicalcium Silicate (C_2S)	18.10%	--
Tricalcium Aluminate (C_3A)	6.90	--
Tetracalcium Aluminoferrite (C_4AF)	7.10%	--
PHYSICAL PROPERTIES		
Autoclave Expansion	0.74%	0.8 max
Time Vicat	75 min	45 - 375
Compressive Strength at 3 days	24.5 MPa	12.4
7 days	31.7 MPa	19.3
28 days	37.0 MPa	27.6
45 - um Sieve Passing	90.5%	--
Blaine Fineness	401 m^2/kg	--

Table 2. Analysis of Normal Aggregates used in Concrete Mixes

AGGREGATE	SPECIFIC GRAVITY	STANDARD SIEVE SIZE (mm)	PERCENT PASSING	
			SPECIFIED	MEASURED
FINE	2.665	9.50	100	100
		4.75	100 - 95	98.8
		2.36	100 - 80	89.0
		1.18	85 - 50	75.2
		0.60	60 - 25	50.4
		0.50	30 - 10	18.8
		0.15	10 - 2	3.6
		0.075	3 - 0	1.4
COARSE	2.716	25.0	100 - 90	100
		19.0	85 - 40	84.3
		12.5	40 - 10	15.6
		9.5	15 - 0	1.3
		4.75	5 - 0	0.3
		2.36		0.2

The spacing factor was determined from Power's equations, assuming a paste content of 26%. The actual paste content in the mix varied from 23 to 29% but it was felt satisfactory to use an average value of 26% in the preliminary tests. As can be seen from the above table, the air contents, the diameter of the air bubbles and the spacing factors in the four mixes had relatively close values. Also when the air contents are plotted in Fig.9, they show good linear relationship between themselves with coefficients of correlation equal to 0.94 for the Linear Traverse Method and 0.97 for the Image Processing Method.

DISCUSSION AND CONCLUSIONS:

It was not easy to come up with the right equipment to start with and hence several trials were needed before a satisfactory set up was achieved. Also the procedure and the technique of testing had to be altered several times until the ones outlined earlier became acceptable and gave consistent results. The final set up and procedure wich were described in detail before gave the most encouraging results that were summarized in Table 3. Certainly,there is need as yet to do a large number of tests to cover many variables that affect the air-void system in concrete. Also, the applicability of the Image processing test in the field should be given careful consideration so as to determine its economic feasibility. There is no doubt that the Image processing method has one main advantage over the other methods in that it gives a complete picture of the air void system in one test only. It takes considerably less effort and less time than the microscopic linear traverse method. The most suitable set of equipment and procedure has to be selected and fine tuned as yet.

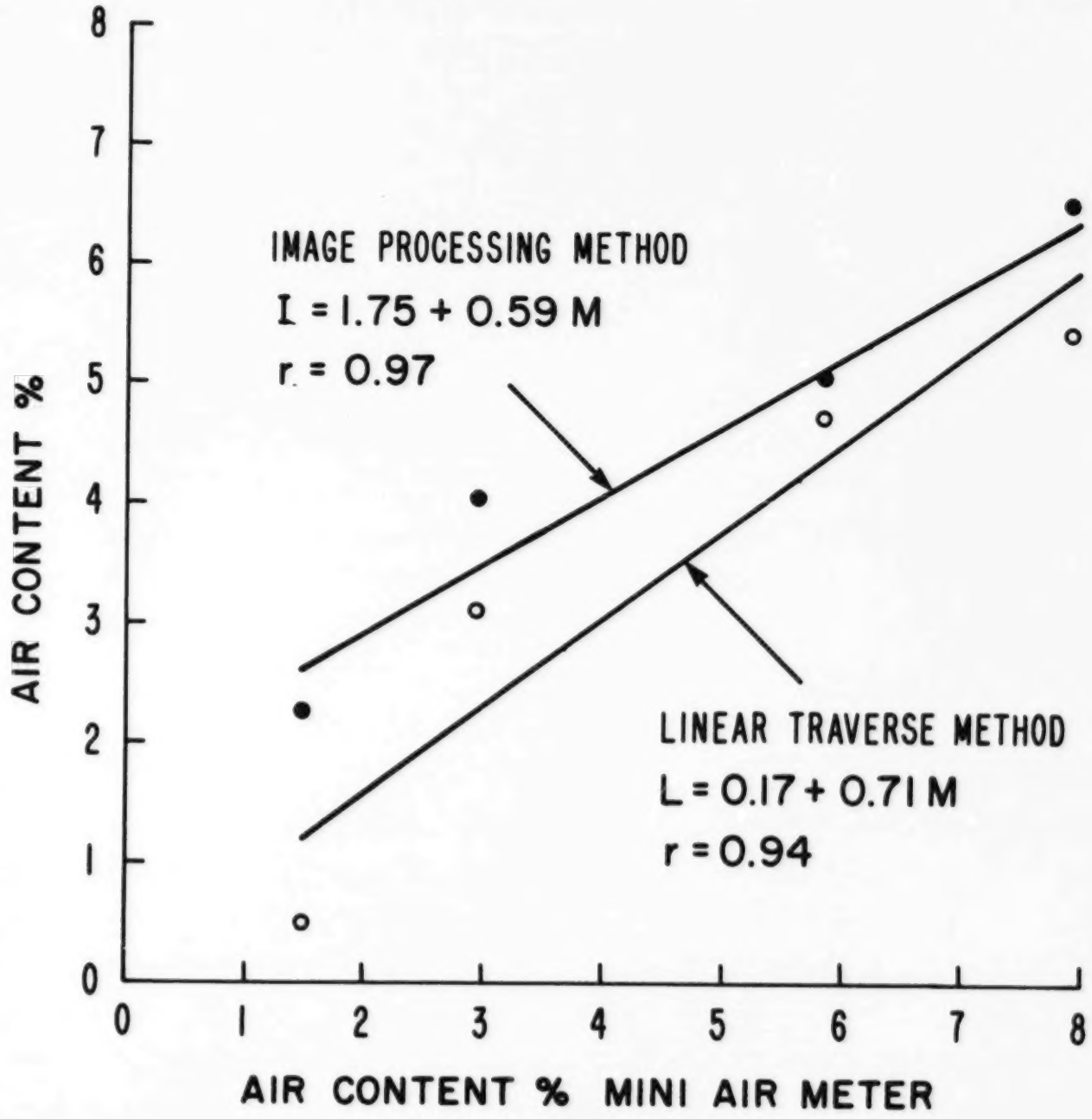


Fig. 9.

Relationship Between Air Contents as Determined by the Mini Air Meter, the Image Processing and the Linear Traverse Methods

In summary, the main conclusion from this project is that the described equipment, set up and procedure had provided a satisfactory method to measure the air-void system in fresh concrete. Additional tests are required to verify its accuracy over a wide range of concrete mixtures.

ACKNOWLEDGEMENT

The author is indebted to Dr. V. M. Malhotra for his enthusiastic support of new innovations in concrete technology.

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APPENDIX

PROGRAM TO DETERMINE THE AIR VOID SYSTEM OF FRESH CONCRETE

```
C*************************************************************************
C*                                                                       *
C*      PROGRAM TO DETERMINE THE AIR VIOD SYSTEM OF FRESH CONCRETE       *
C*                                                                       *
C*                                                                       *
C*                                                                       *
C*************************************************************************
C
C       DECLARATION
        IMPLICIT INTEGER(A-Z)
        INCLUDE 'COMTAL:COMTAL.HDR'
        BYTE IMDATA(264000)
        BYTE IMDAT(264000)
        INTEGER*2 MAXINT,VALUE
        INTEGER*2 XTL,XLR,YTL,YLR,CORNER(4)
        INTEGER*2 INTENS(512,512),IN(255),XAXIS(255)
        INTEGER*4 COUNT(255)
        INTEGER*4 IMROW,IMCOL,NROW,NCOL
        REAL*4 AIR,AVEDIA,AVE,AVESPC,SPACE,MAX
        REAL*4 PASTE,AFLA,RATIO
        REAL*4 TEMDIA(200),TEMSPC(200),D(512),B(512)
        REAL*4 PERCNT(255),SUM,YAXIS(256),SLOP2,SLOP1
        REAL*4 FACTOR,FACT,FACT1,FACT2,SCALE
        CHARACTER INFILE*15,ACR*5,WCR*6,DATE*15
        DATA IMROW/512/
        DATA IMCOL/512/
        DATA NTRY/300/
        DATA WIDTH/6/
        DATA FACTOR/93.0/
        DATA FACT1/22.0/
        DATA FACT/163.0/
C
C       DESCRIPTION
C
        WRITE(5,*)
        WRITE(5,*)
        WRITE(5,*)
        WRITE(5,*) '*************************************************************'
        WRITE(5,*) '                          INTRODUCTION                       '
        WRITE(5,*) ' This  program uses  the COMTAL PROGRAMMING ROUTINES  to'
        WRITE(5,*) ' analyse  the properties of air  content in  concrete by'
        WRITE(5,*) ' means  of image  digitization technique  on the COMTAL.'
        WRITE(5,*) ' These routines provide an interface between the College'
        WRITE(5,*) ' of Engineering VAX 11/780 and the COMTAL vision one/20.'
        WRITE(5,*) '                                                         '
        WRITE(5,*) ' TO continue this program, a digitized image file of the'
        WRITE(5,*) ' air entrained  concrete must  be stored in the VAX, and'
        WRITE(5,*) ' the image is stored in a LINEAR array of BYTE form. Any'
        WRITE(5,*) ' number between -128 and -1 in the array will be changed'
        WRITE(5,*) ' as 128 TO 225 for the purpose of analysis.              '
        WRITE(5,*) '                                                         '
        WRITE(5,*) '   ***** Now make sure the COMTAL SYSTEM is "ON" *****   '
        WRITE(5,*) '                                                         '
        WRITE(5,*) '*************************************************************'
        WRITE(5,*)
        WRITE(5,*)
C
C       OPEN INPUT AND OUTPUT FILES
C
        WRITE(5,*) 'ENTER IMAGE FILE NAME:'
        READ(5,10) INFILE
10      FORMAT (A15)
        TYPE*, 'READ IMAGE FILE'
15      OPEN(UNIT=01,STATUS='OLD',FILE=INFILE,FORM='UNFORMATTED',
     1       RECORDTYPE='FIXED',RECL=128)
```

```
      DO 20 ROW=1,IMROW
20      READ(01) (IMDATA((ROW-1)*IMCOL+COL),COL=1,IMCOL)
      CLOSE(UNIT=01)
      OPEN(UNIT=03,STATUS='UNKNOWN',FILE='AIRTEST.DAT')
      WRITE(03,*) 'IMAGE FILE NAME: ',INFILE
      OPEN(UNIT=04,STATUS='UNKNOWN',FILE='TEMP.DAT')
C
C     INPUT INFORMATION OF THE TEST SAMPLE
C
      WRITE(5,*) 'ENTER AGGREGATE/CEMENT RATIO:'
      READ(5,1) ACR
1     FORMAT (A5)
      WRITE(5,*) 'ENTER WATER/CEMENT RATIO:'
      READ(5,3) WCR
3     FORMAT (A5)
      WRITE(5,*) 'ENTER BATCHING DATE:'
      READ(5,5) DATE
5     FORMAT (A15)
      WRITE(5,*)
C
C     TRANSFER PHOTO IMAGE FROM VAX (SKENG) TO COMTAL
C
C     ALLOCATE THE COMTAL IMAGE PROCESSOR
C
      TRY=1
      STATUS=CWGRAB()
      IF (STATUS .NE. 1) GOTO 1000
C
C     DEFINE WINDOW SIZE
C
      IMNUM=1
      CORNER(1)=0
      CORNER(2)=0
      CORNER(3)=511
      CORNER(4)=511
320   STATUS=CWWINDOW(SEND,IMAGE,IMNUM,CORNER)
      IF (STATUS .EQ. 1) GOTO 330
      IF (TRY .GT. NTRY) GOTO 1010
      TRY=TRY+1
      GOTO 320
330   WRITE(5,*) '***** ENTERING CORNERS SET OF ORIGINAL IMAGE *****'
      WRITE(5,*) '***** SENDING PHOTO IMAGE TO COMTAL DISPLAY *****'
      TRY=1
335   STATUS=CWCOPY(SEND,IMAGE,IMNUM,IMDATA)
      IF (STATUS .EQ. 1) GOTO 340
      IF (TRY .GT. NTRY) GOTO 1020
      TRY=TRY+1
      GOTO 335
340   WRITE(5,*) '***** PHOTO IMAGE SENT TO IMAGE PROCESSOR NO 1 *****'
C
C     CHANGE THE IMAGE DATA (LINEAR ARRAY) INTO TWO DIMENSIONAL ARRAY
C
      DO 21 ROW=1,IMROW
      DO 21 COL=1,IMCOL
        VALUE=IMDATA((ROW-1)*IMCOL+COL)
        IF (VALUE .LT. 0) VALUE=VALUE+256
        INTENS(ROW,COL)=VALUE
21    CONTINUE
C
C     ANALYSE PHOTO IMAGE
C
      WRITE(5,*)
26    WRITE(5,*) 'ENTER SIZE OF THE SECTION IMAGE [ROW,COLUMN]'
      READ(5,*) NROW,NCOL
      TEMP1=MOD(NROW,2)
```

```
      TEMP2=MOD(NCOL,2)
      IF (TEMP1 .NE. 0 .OR. TEMP2 .NE. 0) THEN
        WRITE(5,*) '***** ERROR *****: THE SIZE OF IMAGE MUST BE EVEN'
        GOTO 26
      ENDIF
        WRITE(5,*) 'ENTER (X,Y) CO-ORDINATES OF TOP LEFT CORNER '
        WRITE(5,*) 'OF THE SECTION IMAGE:'
        READ(5,*) XTL,YTL
        XLR=XTL+(NCOL-1)
        YLR=YTL+(NROW-1)
        CORNER(1)=XTL
        CORNER(2)=YTL
        CORNER(3)=XLR
        CORNER(4)=YLR
C
C       STATISTICAL ANALYSIS OF IMAGE
C
        IF (MOD(255,WIDTH) .NE. 0) GOTO 30
        NWIDTH=255/WIDTH
        GOTO 40
30      NWIDTH=255/WIDTH+1
40      DO 50 J=1,NWIDTH
          PERCNT(J)=0
          IN(J)=0
          COUNT(J)=0
50      CONTINUE
C
        WRITE(5,*)
        WRITE(5,*) 'PROCESSING SECTION IMAGE : *** WAIT ***'
        DO 90 ROW=YTL,YLR
        DO 80 COL=XTL,XLR
          VALUE=INTENS(ROW,COL)
          I=WIDTH
          IF (VALUE .LT. 0) VALUE=VALUE+256
60        IF (VALUE .LE. I) THEN
            VALUE=I
            J=I/WIDTH
            GOTO 70
          ELSE
            I=I+WIDTH
            J=I/WIDTH
            IF (J .LE. NWIDTH) GOTO 60
          ENDIF
70        IN(J)=VALUE
          COUNT(J)=COUNT(J)+1
80      CONTINUE
90      CONTINUE
C
C       DETERMINE MAXIMUM INTENSITY OF AIR VOIDS
C
        SUM=0.0
        K=0
        DO 110 J=1,NWIDTH
          IF (COUNT(J) .EQ. 0) GOTO 110
          PERCNT(J)=(FLOAT(COUNT(J))/(NROW*NCOL))*100
          SUM=PERCNT(J)+SUM
          K=K+1
          XAXIS(K)=IN(J)
          YAXIS(K)=SUM
110     CONTINUE
        DO 111 I=2,K-1
          X2=XAXIS(I+1)-XAXIS(I)
          X1=XAXIS(I)-XAXIS(I-1)
          SLOP2=(YAXIS(I+1)-YAXIS(I))/X2
          SLOP1=(YAXIS(I)-YAXIS(I-1))/X1
```

```
          YAXIS(I-1)=(SLOP2-SLOP1)/((X2+X1)/2)
          XAXIS(I-1)=XAXIS(I)
111     CONTINUE
        MAX=0
        DO 112 I=1,K-2
          IF (YAXIS(I) .GT. MAX) THEN
            MAX=YAXIS(I)
            MAXINT=FACTOR*XAXIS(I)/100
          ENDIF
112     CONTINUE
        WRITE(5,*) 'MAXIMUM INTENSITY OF AIR VOIDS:',MAXINT
C
C       MODIFY SECTION IMAGE
C
        MININT=0
        IMNUM=1
        DO 400 R=YTL,YLR
        DO 400 C=XTL,XLR
          IF (INTENS(R,C) .LT. MININT .OR. INTENS(R,C) .GT. MAXINT) GOTO 380
          INTENS(R,C)=0
          GOTO 390
380       INTENS(R,C)=255
390       VALUE=INTENS(R,C)
          IF (VALUE .GT. 127) VALUE=VALUE-256
          ROW=R-(YTL-1)
          COL=C-(XTL-1)
          IMDAT((ROW-1)*NCOL+COL)=VALUE
400     CONTINUE
C
C       SEND MODIFIED IMAGE TO COMTAL
C
        TRY=1
410     STATUS=CWWINDOW(SEND,IMAGE,IMNUM,CORNER)
        IF (STATUS .EQ. 1) GOTO 420
        IF (TRY .GT. NTRY) GOTO 1010
        TRY=TRY+1
        GOTO 410
420     WRITE(5,*) '***** SENDING MODIFIED SECTION IMAGE *****'
        TRY=1
430     STATUS=CWCOPY(SEND,IMAGE,IMNUM,IMDAT)
        IF (STATUS .EQ. 1) GOTO 440
        IF (TRY .GT. NTRY) GOTO 1020
        TRY=TRY+1
        GOTO 430
440     WRITE(5,*) '***** MODIFIED IMAGE SENT *****'
C
C       COMPUTE AVE. % OF AIR CONTENT IN SECTION IMAGE
C
        ICOUNT=0
        DO 125 ROW=YTL,YLR
        DO 120 COL=XTL,XLR
          IF (INTENS(ROW,COL) .GT. MAXINT) GOTO 120
          ICOUNT=ICOUNT+1
120     CONTINUE
125     CONTINUE
        AIR=(FLOAT(ICOUNT)/FLOAT(NCOL*NROW))*100
C
C       DETERMINE THE AVE. CHORD INTERCEPT OF AIR VOIDS
C
C       IMAGE SIZE: FACT2 = [ X mm/512 pix ]
        FACT2 = FACT/512
        SCALE=FACT2/FACT1
        DO 210 ROW=YTL,YLR
        DO 200 COL=XTL,XLR
          IF (INTENS(ROW,COL) .GT. MAXINT) THEN
```

```
            INTENS(ROW,COL)=255
          ELSE
            INTENS(ROW,COL)=0
          ENDIF
200     CONTINUE
210     CONTINUE
        SCOUNT=0
        DCOUNT=0
        DO 250 ROW=YTL,YLR
          J=1
          K=1
        DO 240 COL=XTL,XLR
          IF (COL .NE. XTL) GOTO 220
          IF (INTENS(ROW,COL) .GT. 0) THEN
            SCOUNT=1
          ELSE
            DCOUNT=1
          ENDIF
          GOTO 240
220       IF (INTENS(ROW,COL) .NE. INTENS(ROW,(COL-1))) GOTO 230
          IF (INTENS(ROW,COL) .GT. 0) THEN
            SCOUNT=SCOUNT+1
          ELSE
            DCOUNT=DCOUNT+1
          ENDIF
          GOTO 235
230       IF (INTENS(ROW,COL) .GT. 0) THEN
            TEMDIA(K)=DCOUNT
            K=K+1
            SCOUNT=1
          ELSE
            TEMSPC(J)=SCOUNT
            J=J+1
            DCOUNT=1
          ENDIF
235       IF (COL .EQ. XLR) THEN
            IF (INTENS(ROW,COL) .GT. 0) THEN
              TEMSPC(J)=SCOUNT
              K=K-1
              IF (K .EQ. 0) K=1
            ELSE
              TEMDIA(K)=DCOUNT
              J=J-1
              IF (J .EQ. 0) J=1
            ENDIF
            AVEDIA=0
            AVESPC=0
            DO 237 I=1,J
              AVESPC=AVESPC+TEMSPC(I)
237         CONTINUE
            DO 238 I=1,K
              AVEDIA=AVEDIA+TEMDIA(I)
238         CONTINUE
            AVESPC=SCALE*AVESPC/J
            AVEDIA=SCALE*AVEDIA/K
            IF (AVESPC .EQ. SCALE*NCOL .OR. AVEDIA .EQ. 0) GOTO 239
            WRITE(04,*) J,AVESPC,K,AVEDIA
239       ENDIF
240     CONTINUE
250     CONTINUE
        CLOSE(UNIT=04)
        OPEN(UNIT=09,STATUS='OLD',FILE='TEMP.DAT',DISPOSE='DELETE')
C       OPEN(UNIT=09,STATUS='OLD',FILE='TEMP.DAT')
        DO 255 I=1,512
          D(I)=0
```

```
255     CONTINUE
        I=0
260     I=I+1
        READ(09,*,END=270) A,B(I),C,D(I)
        GOTO 260
270     CLOSE(UNIT=09)
        AVEDIA=0
        II=I-1
        DO 275 J=1,II
          AVEDIA=D(J)+AVEDIA
275     CONTINUE
        AVE=AVEDIA/II
C
C       COMPUTE SPACE FACTOR OF AIR VOID IN CONCRETE
C
        PASTE=26.0
        ALFA=4.0/AVE
        RATIO=PASTE/AIR
        IF (RATIO .GT. 4.342) THEN
          SPACE=(3.0/ALFA)*(1.4*(RATIO+1)**0.333333-1)
        ELSE
          SPACE=PASTE/(AIR*ALFA)
        ENDIF
C
C       OUTPUT TEST RESULTS
C
        WRITE(5,*)
        WRITE(5,*) '% AIR CONTENT IN SECTION IMAGE:',AIR
        WRITE(5,*) 'AT INTENSITY LEVEL',MAXINT
        WRITE(5,*)
        WRITE(5,*) 'AVE CHORD INTERCEPT:',AVE
        WRITE(5,*) 'SPACING FACTOR:',SPACE
        WRITE(5,*)
        WRITE(03,*)
        WRITE(03,*) 'CONCRETE MIX DESIGN'
        WRITE(03,*) 'A/C:',ACR,'W/C:',WCR
        WRITE(03,*) 'BATCHING DATE:',DATE
        WRITE(03,*)
        WRITE(03,*) 'START CORNER OF SECTION IMAGE'
        WRITE(03,*) XTL,YTL
        WRITE(03,*) 'SIZE OF SECTION IMAGE:',NROW,NCOL
        WRITE(03,*)
        WRITE(03,*) '% AIR CONTENT IN SECTION IMAGE:',AIR
        WRITE(03,*) 'AT INTENSITY LEVEL',MAXINT
        WRITE(03,*)
        WRITE(03,*) 'AVE CHORD INTERCEPT:',AVE
        WRITE(03,*) 'SPACING FACTOR:',SPACE
        CLOSE(UNIT=03)
        WRITE(5,*) '******* DONE *******'
        GOTO 1100
C
C       ERROR MESSAGE
C
1000    WRITE(5,*) '*** ERROR IN COMTAL ROUTINE: CMGRAB ***'
        GOTO 1100
1010    WRITE(5,*) '*** ERROR IN COMTAL ROUTINE: CMWINDOW ***'
        GOTO 1030
1020    WRITE(5,*) '*** ERROR IN COMTAL ROUTINE: CMCOPY ***'
1030    WRITE(5,*) '     NO. OF TRIAL EXCEED LIMIT [300]; STATUS:',STATUS
1100    STOP
        END
```